THERMAL REMEDIATION services inc.

30th Environmental & Energy Symposium & Exhibition

NATIONAL DEFENSE INDUSTRIAL ASSOCIATION

In Situ Thermal Remediation Using Electrical Resistance Heating (ERH)

April 7, 2004

David Fleming
425-396-4266
dfleming@thermalrs.com
www.thermalrs.com

What is Electrical Resistance Heating?

- Takes common 3-phase electricity and directs it into the subsurface through electrodes
- Electrodes and co-located vapor recovery or multi-phase extraction wells can be placed vertically or horizontally to any depth
- Once in the subsurface, the electrical energy resistively heats soil and groundwater
- Contaminants are removed by direct volatilization, *in situ* steam stripping, and entrainment extraction

THERMAL REMEDIATION services inc.

Why Electrical Resistance Heating?

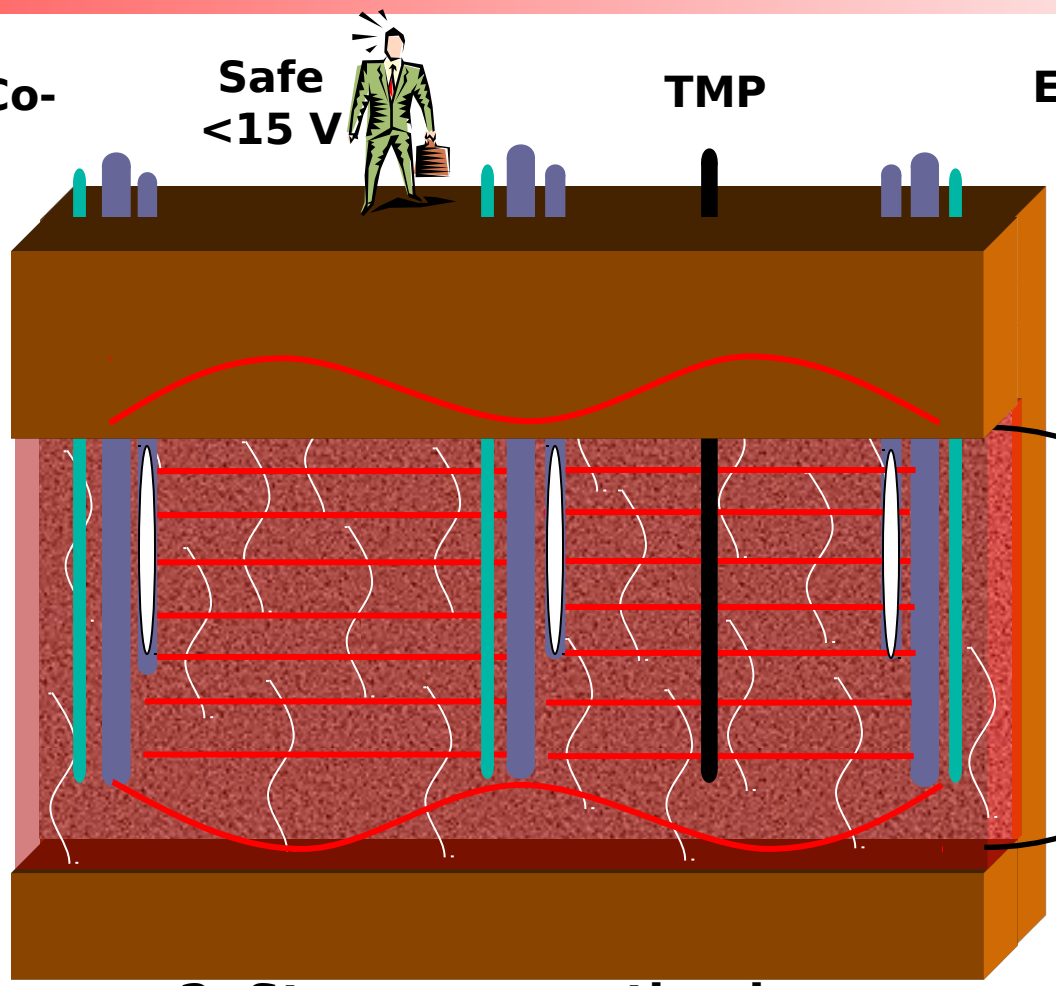
- **Effective in vadose and saturated zones**
- **Heating is uniform with no bypassed regions**
- **Heating is rapid – cleanup in months vs. years**
- **Steam is produced *in situ* - not pressure injected**
- **Preferentially heats tight soil lenses**
- **Preferentially heats NAPL hot spots**
- **Cost effective**
  - Pricing for commercial sites range from $30-$90 per yds^3
  - Pricing is dependent upon site conditions & cleanup goals

THERMAL REMEDIATION services inc.

Applications

- **Soil and groundwater remediation**
- **Heterogeneous & Low permeability lithologies**
- **BTEX, fuels, and chlorinated hydrocarbons**
- **LNAPL & DNAPL cleanups**
  - Aquifer boiling
  - Smear zone heating
- **Heavy hydrocarbon mobilization and recovery**
- **Bioremediation enhancement**
- **Remediation underneath operating facilities**
- **Remediation in the presence of buried utilities**

In-Situ Steam Generation



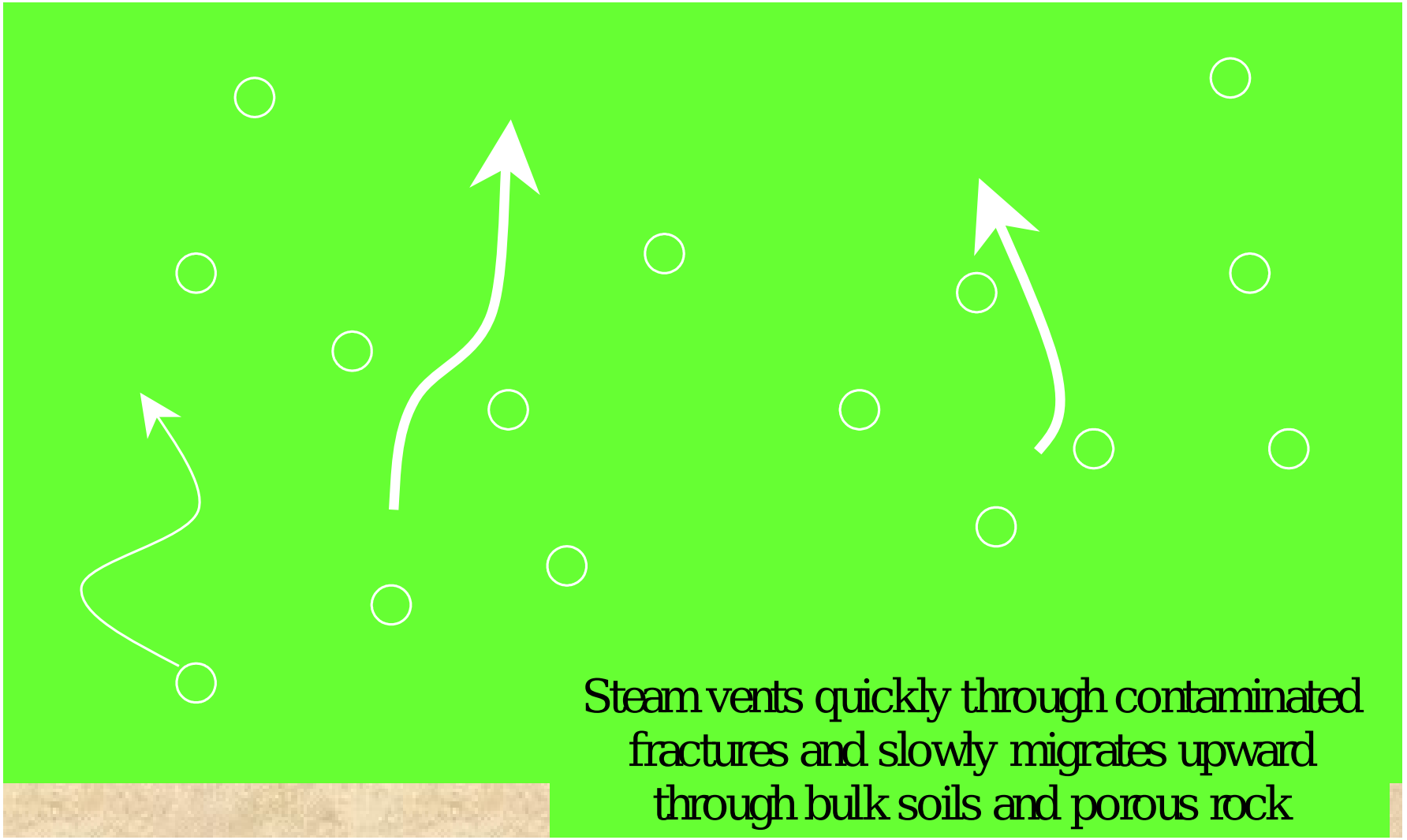
1. Soil grains act as electrical resistors

2. Steam generation is uniform through the heated zone

3. Discrete intervals can be heated

THERMAL REMEDIATION services inc.

In-Situ Steam Venting



Steam vents quickly through contaminated fractures and slowly migrates upward through bulk soils and porous rock

THERMAL REMEDIATION services inc.

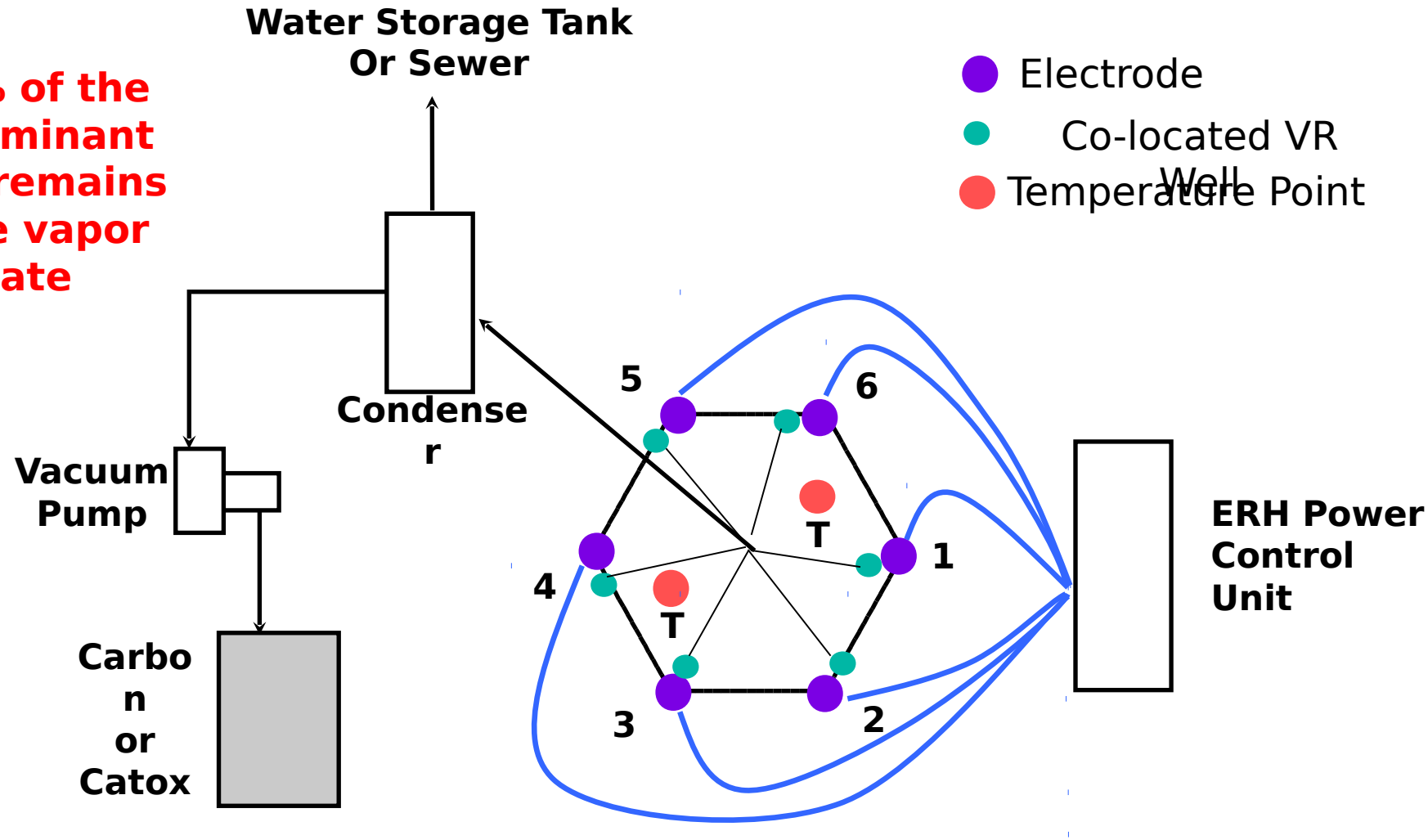
Typical Surface Equipment

Photo Courtesy of Brown and Caldwell

Vapor Recovery System

THERMAL REMEDIATION services inc.

>99% of the contaminant mass remains in the vapor state



Brownfield Remediation Chicago Suburb – PCE in Soil

- Ruptured sewer line released PCE to soil 300 ft. down-gradient from the drycleaner
- Lithology consists of sediments with clayey glacial till deposit with very low permeability - 10^{-8} cm/sec
- Groundwater: 70 feet bgs
- VOC mass in unsaturated soil: 3,150 lbs. (est.)
- Maximum PCE Concentration: 13,000 mg/kg
- Average Initial Concentration: ~ 5,000 mg/kg
- Area of Contamination: 1,500 square ft.
- Soil Contamination Depth: 4 to 20 feet
- Operating, buried utilities: sewer, water, natural gas, electric
- Guaranteed Performance Based Cleanup Contract

THERMAL REMEDIATION services inc.

Cost Comparison

- **Excavation and Disposal**
  - **Estimated Cost for shoring of building, utility relocation, soil removal, disposal as a hazardous waste, and soil replacement:**

    $1.1 million
- **ERH**
  - **Total fixed price, performance based, guaranteed remediation:**

    $0.695 million

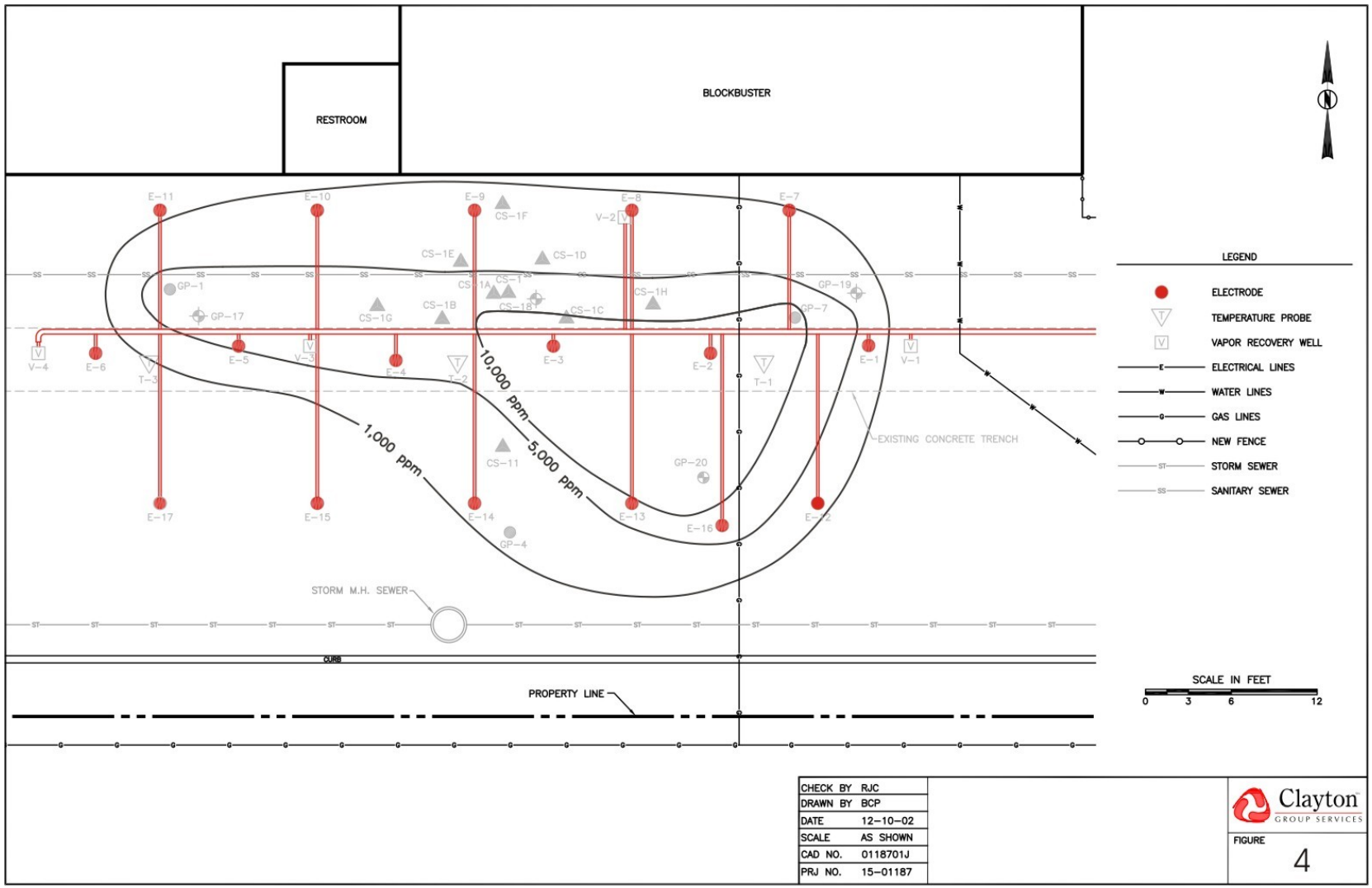
THERMAL REMEDIATION services inc.

Design Parameters

- Remedial objective: remove residual DNAPL in soil to < 529 mg/kg
- Alley remains open to traffic
- 17 electrodes and co-located vapor and steam recovery wells on ~15 foot centers
- 3 additional vapor and steam recovery wells inside common trench
- Horizontal vapor recovery wells
- 3 temperature monitoring points w/ thermocouples every 5 feet
- Electrically conductive from 4 – 20 ft bgs

THERMAL REMEDIATION services inc.

Electrode Layout



Common Utility Trench

- Electrodes
- Vapor and steam recovery wells
- Cables and piping
- Water connections

Courtesy of Clayton

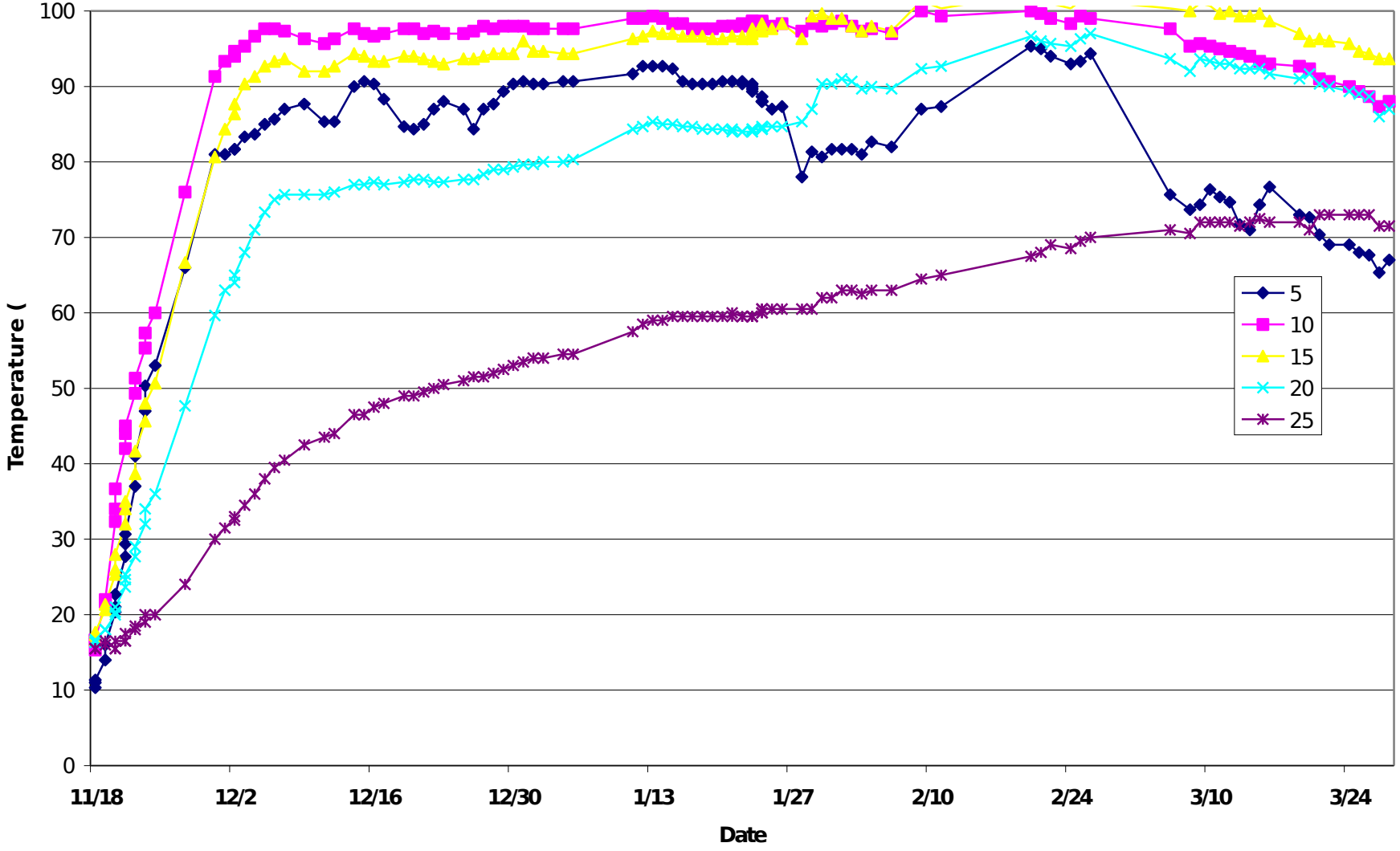
Remediation in Chicago from December – March 2003

Alley Remained Open to Vehicle and Pedestrian Traffic during ERH Operations

Courtesy of Clayton

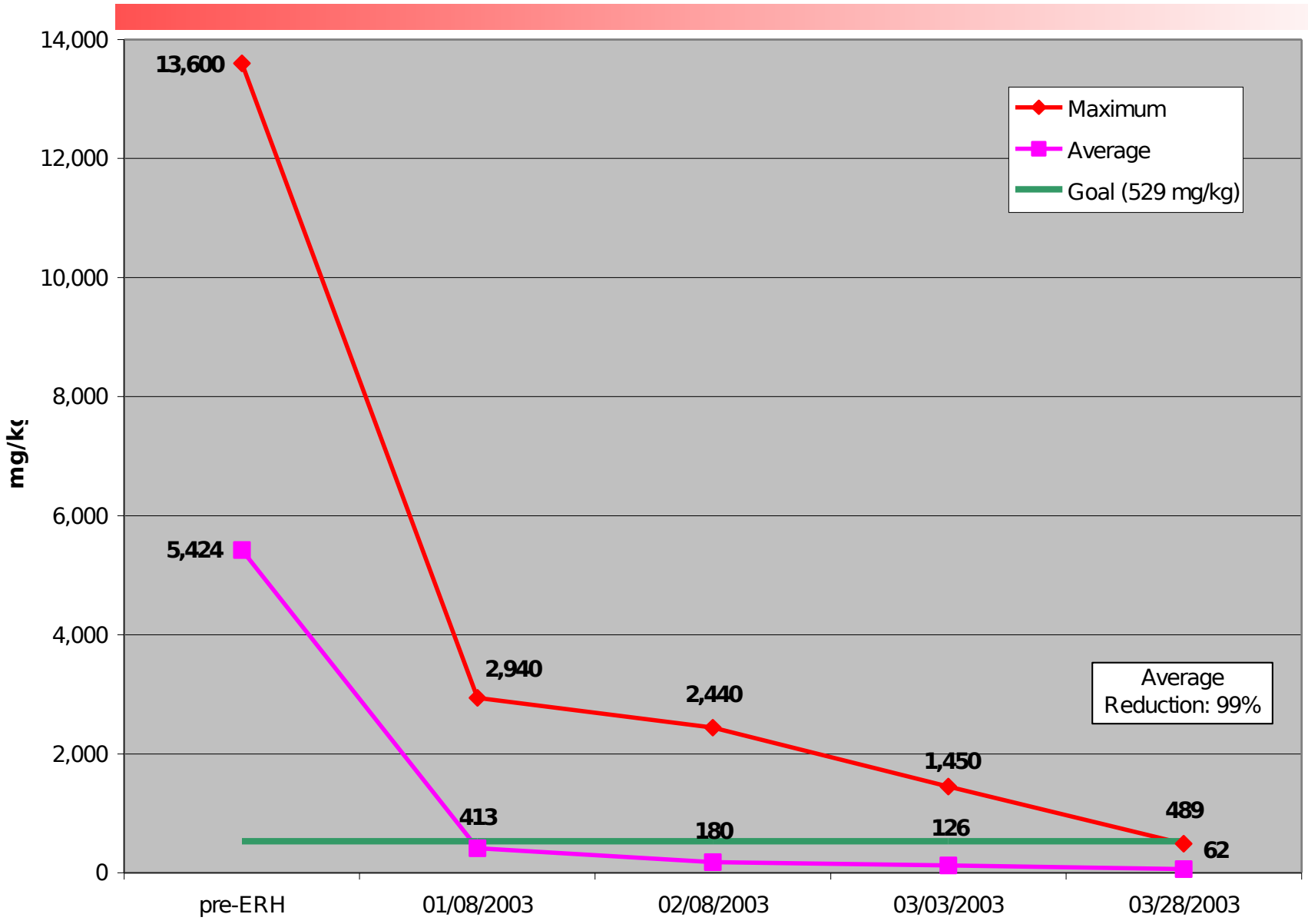
THERMAL REMEDIATION services inc.

Average Subsurface Temperatures



THERMAL REMEDIATION services inc.

Decrease in PCE Concentrations – Pre and Post ERH



Results in Chicago Suburb

- **Operations started on November 18, 2002**
- **Temperatures:**
  - Initial Startup: 14.7 degrees C
  - 30 days: 83.4 degrees C
  - 60 days: 87.8 degrees C
  - 90 days: 93.6 degrees C

- **Total heating time: 120 days**
- **Average final concentration: 62 ppm (based on 60 sampling locations)**
- **Goal was < 529 mg/kg**
- **Final VOC Removal: 2,392 lbs of PCE (March 28, '03)**
- **Maximum Removal Rate: 6 lbs/hour**
- **Letter of No Further Action from the IL EPA**

THERMAL REMEDIATION services inc.

TCE DNAPL Remediation Air Force Plant Four Fort Worth, Texas

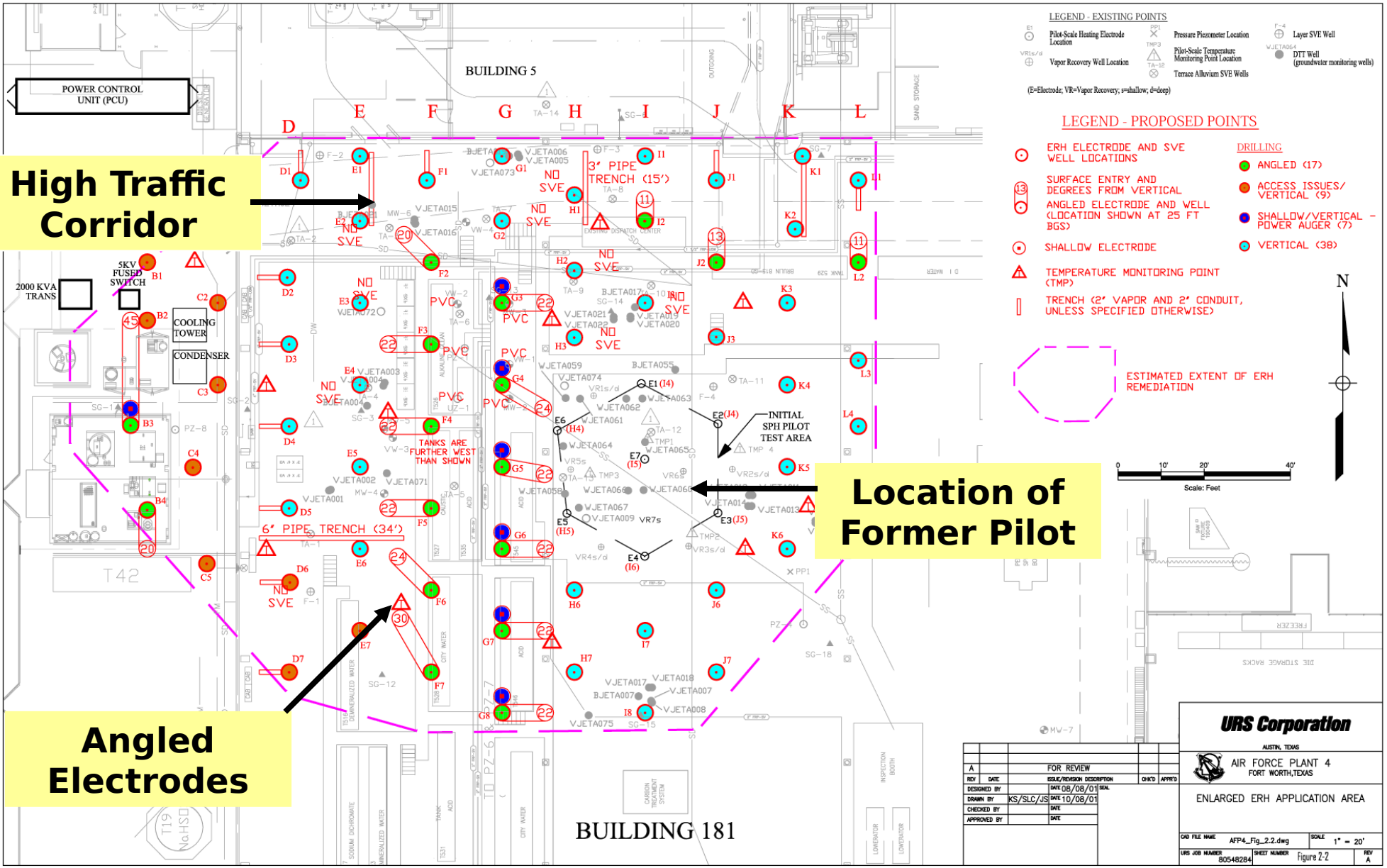
Photo Courtesy of URS

Full-Scale ERH at AF Plant 4

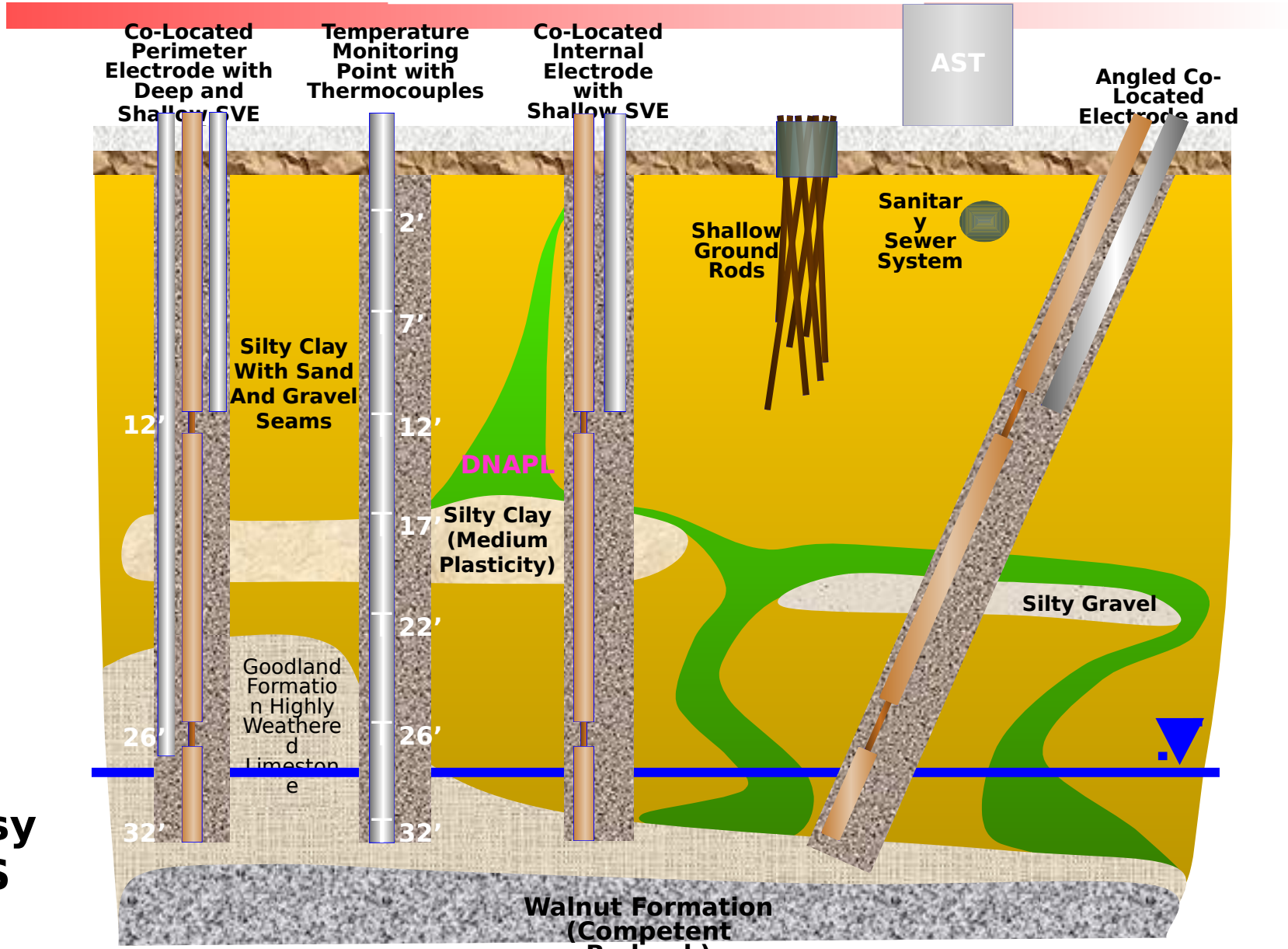
- Full-scale ERH covering 1/2 acre area inside and outside of Bldg. 181, manufacturing operations 24/7
- 70 electrodes and co-located VR wells installed in and around existing tanks, piping and equipment
- Heterogeneous silt, clay and gravel with a highly weathered limestone, competent bedrock at 32 ft bg
- Groundwater at 27 ft bg
- Electrodes electrically conductive 3 to 32 ft bg
- ERH operations May to Aug 2002; reduced area – Dec '02
- **Goal** – average 90% reduction based on a 95% UCL

Full-Scale ERH Layout

THERMAL REMEDIATION services inc.



Full-Scale ERH Subsurface



Courtesy of URS

THERMAL REMEDIATION services inc.

Angled Electrode Boring

Courtesy of URS

ERH Remediation Beneath Air Force Plant Four

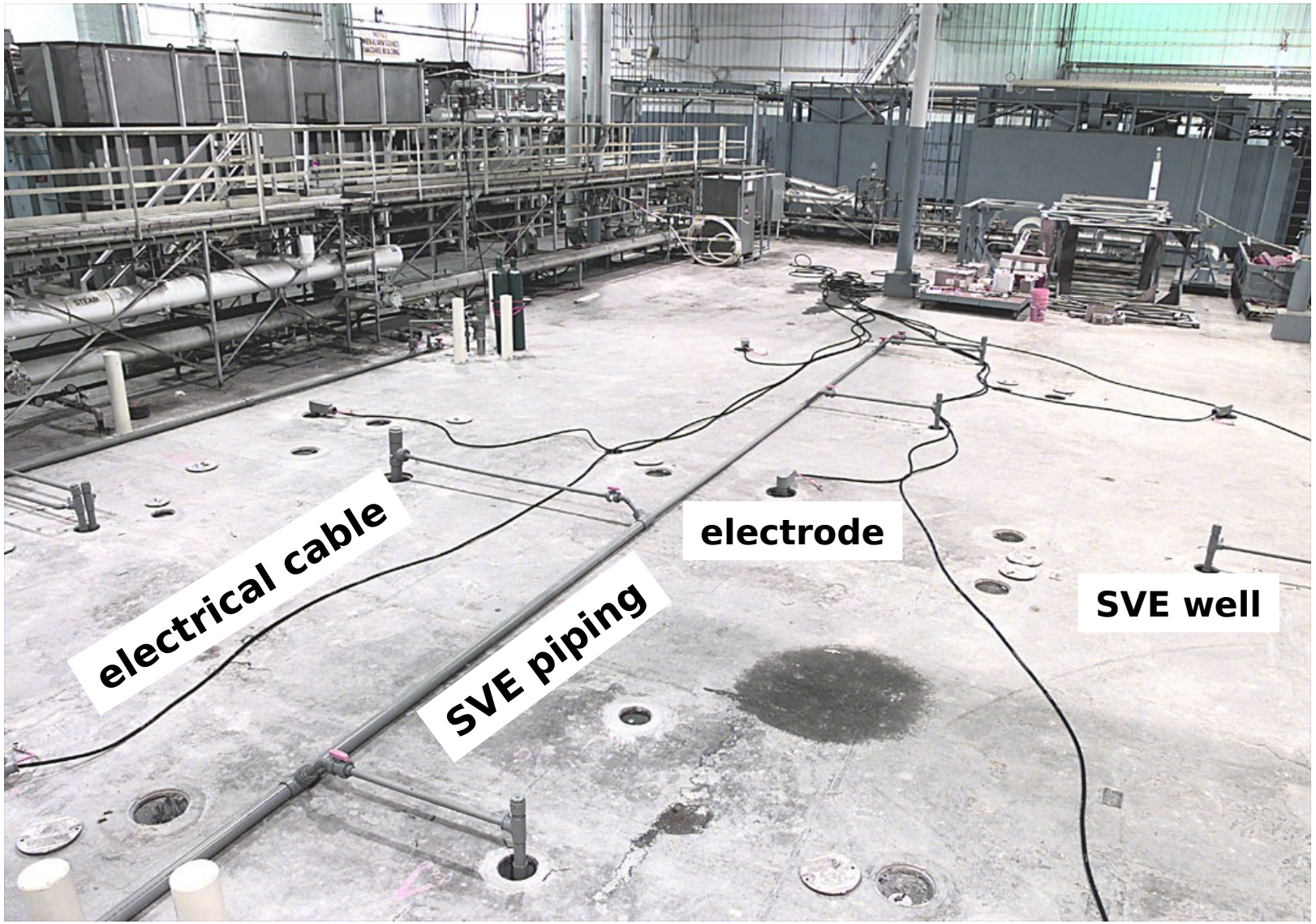


Photo Courtesy of URS

THERMAL REMEDIATION services inc.

Equipment Staging

Photo Courtesy of URS

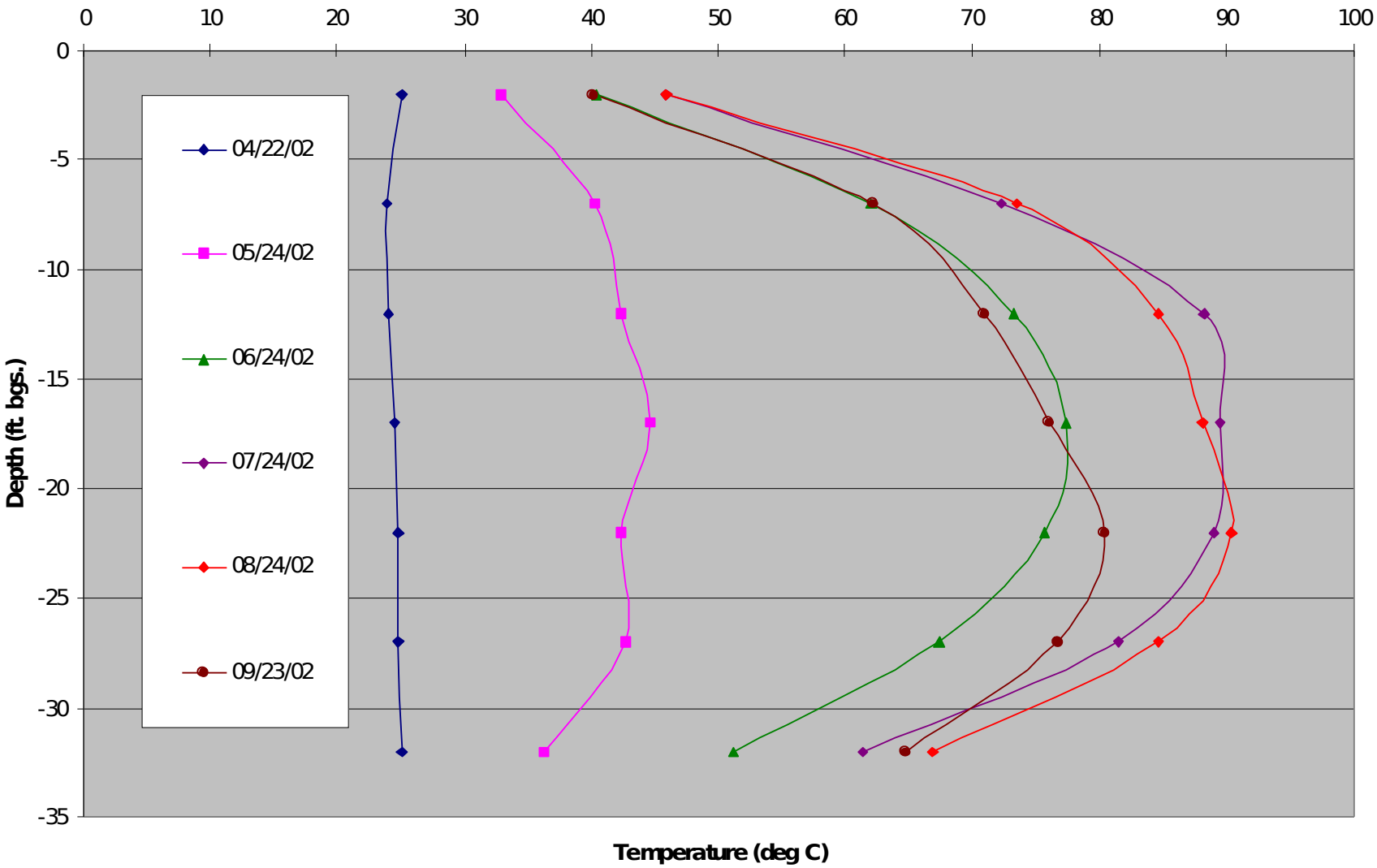
Continuous Indoor Air Monitoring

- URS operated INNOVA System sampled air for TCE every 5 minutes
- Would shutdown ERH system if TCE >3 ppm
- Online remote monitoring
- Never exceeded background TCE concentrations inside Bldg. 181

Courtesy of URS

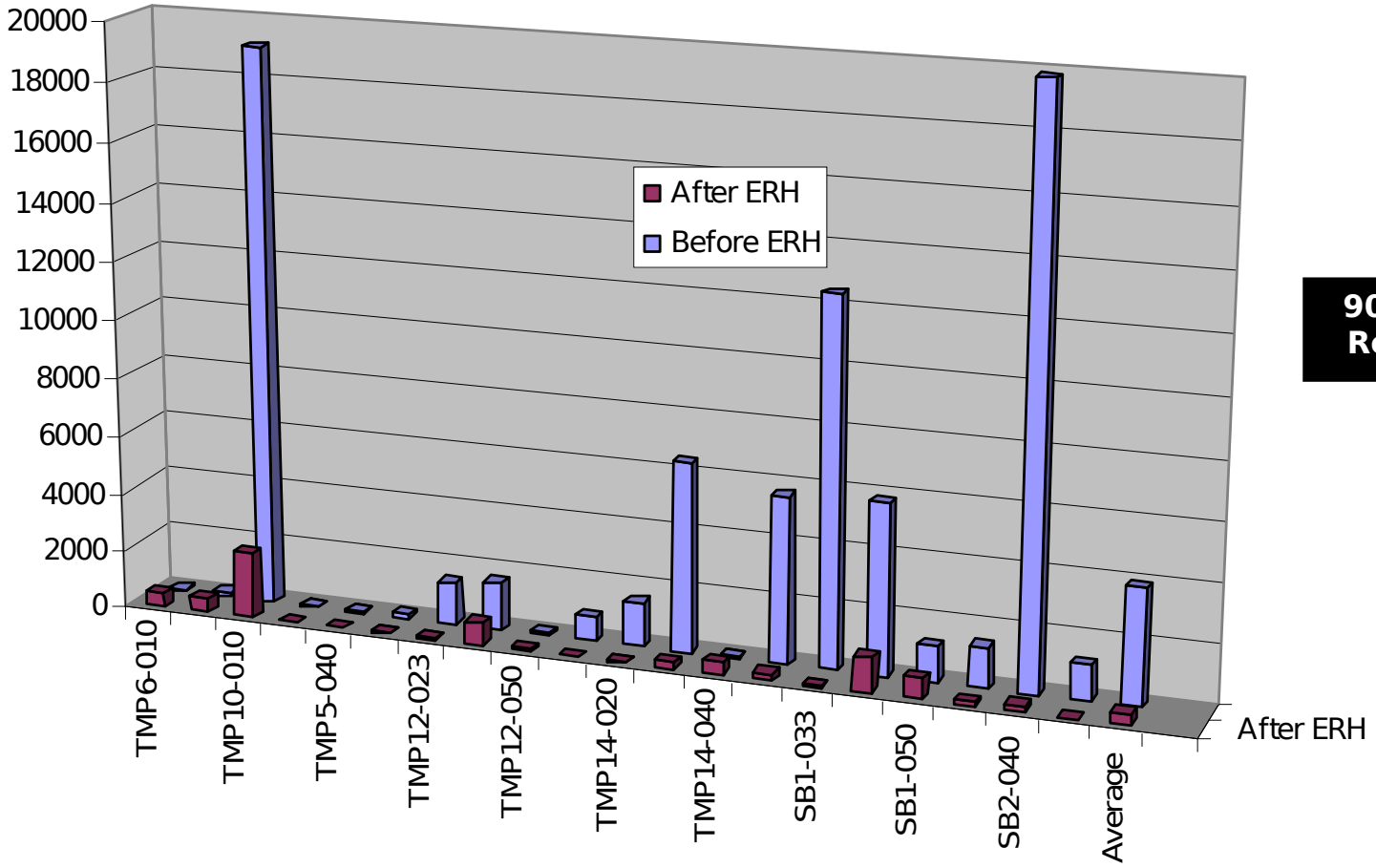
THERMAL REMEDIATION services inc.

Monthly Average Temperature vs. Depth (April – Sept. ’02)



THERMAL REMEDIATION services inc.

Pre and Post Soil Data with Depth

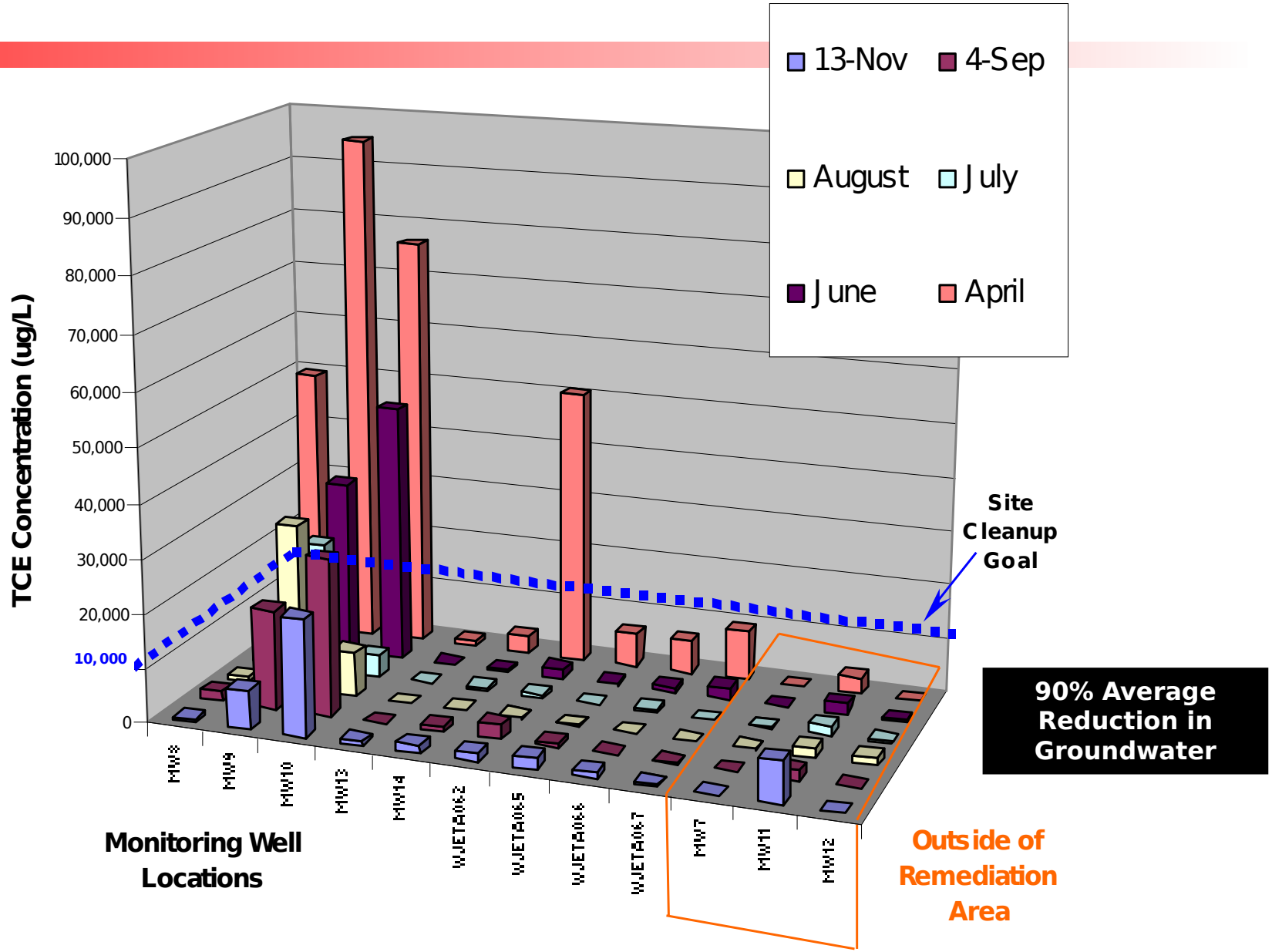


90% Average Reduction in Soil

TCE ug/kg

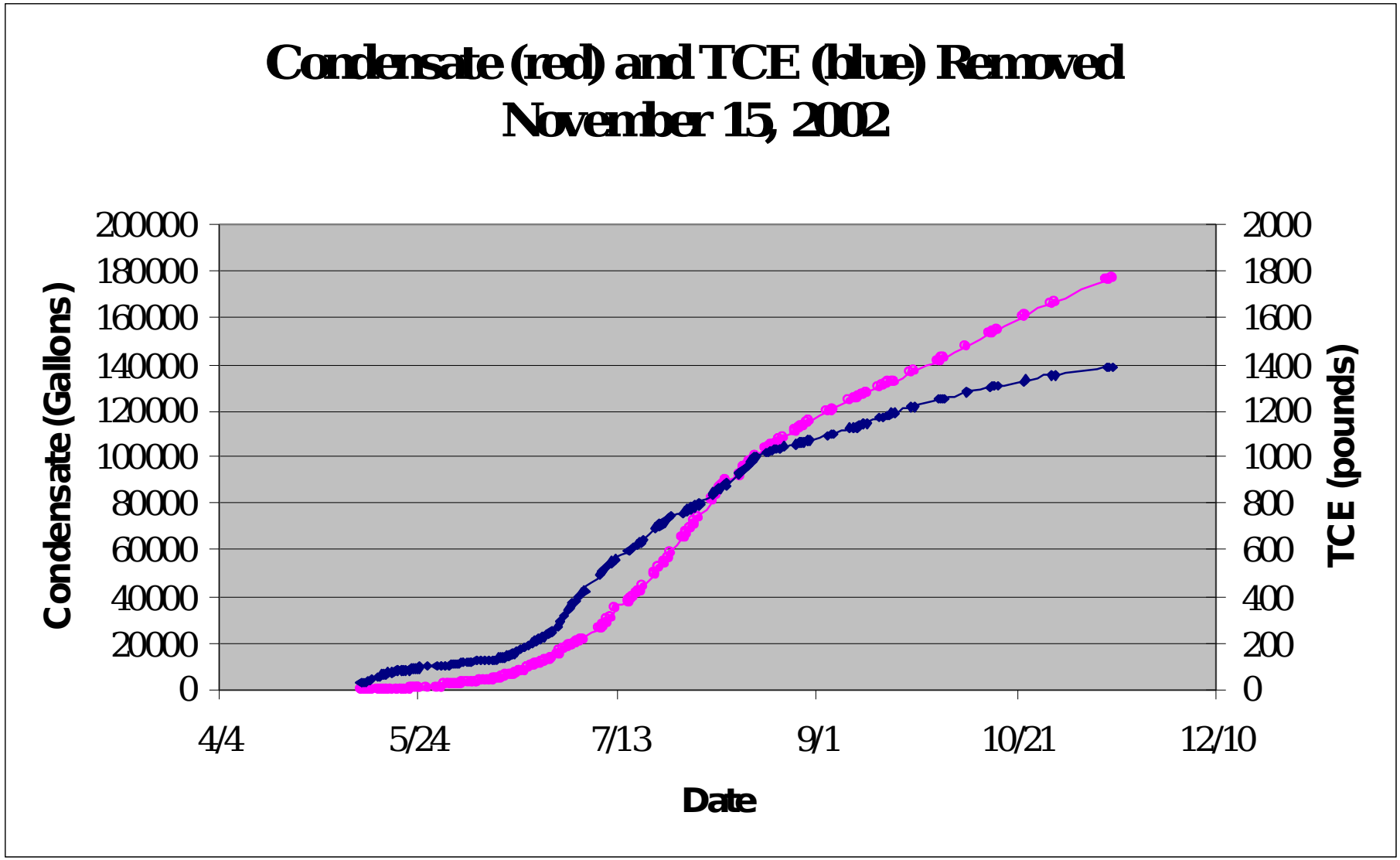
Courtesy of URS

Final TCE Concentrations in Groundwater

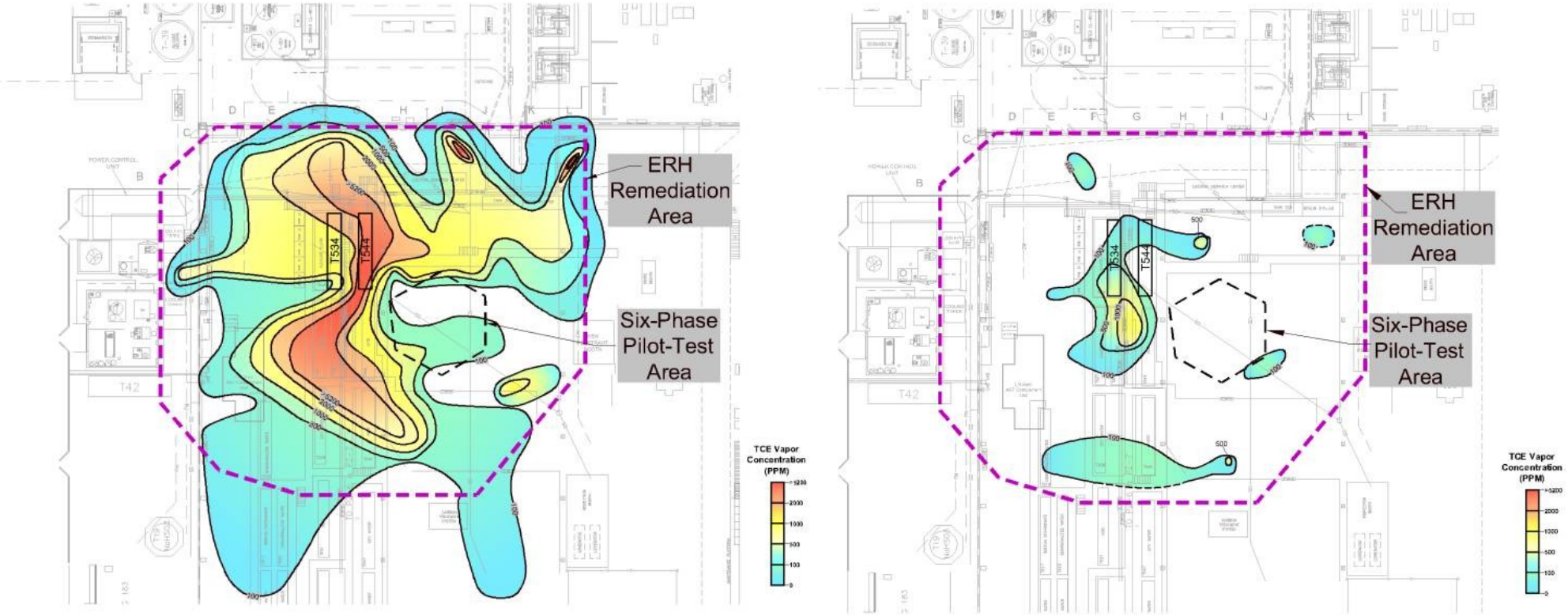


THERMAL REMEDIATION services inc.

TCE Mass Removal



Pre and Post ERH Soil Vapor Results



Courtesy of URS

Results at AF Plant 4

- Area & volume treated - 22,000 sq. ft. & 27,400 cubic yards – from May to Dec 2002
- Average weekly power input – 563 kW
- Recovered ~ 1,400 lbs. TCE
- Met cleanup goals, 90% average reduction
- TCE concentration in MW-10 remain high
- TCE concentrations never exceeded background levels of TCE in the indoor breathing space
- No impacts to manufacturing operations
- ~$57 per cubic yard – ERH cost only
- Evidence of heat enhanced biodegradation

TCE DNAPL Remediation
DOE - Paducah, KY

THERMAL REMEDIATION services inc.

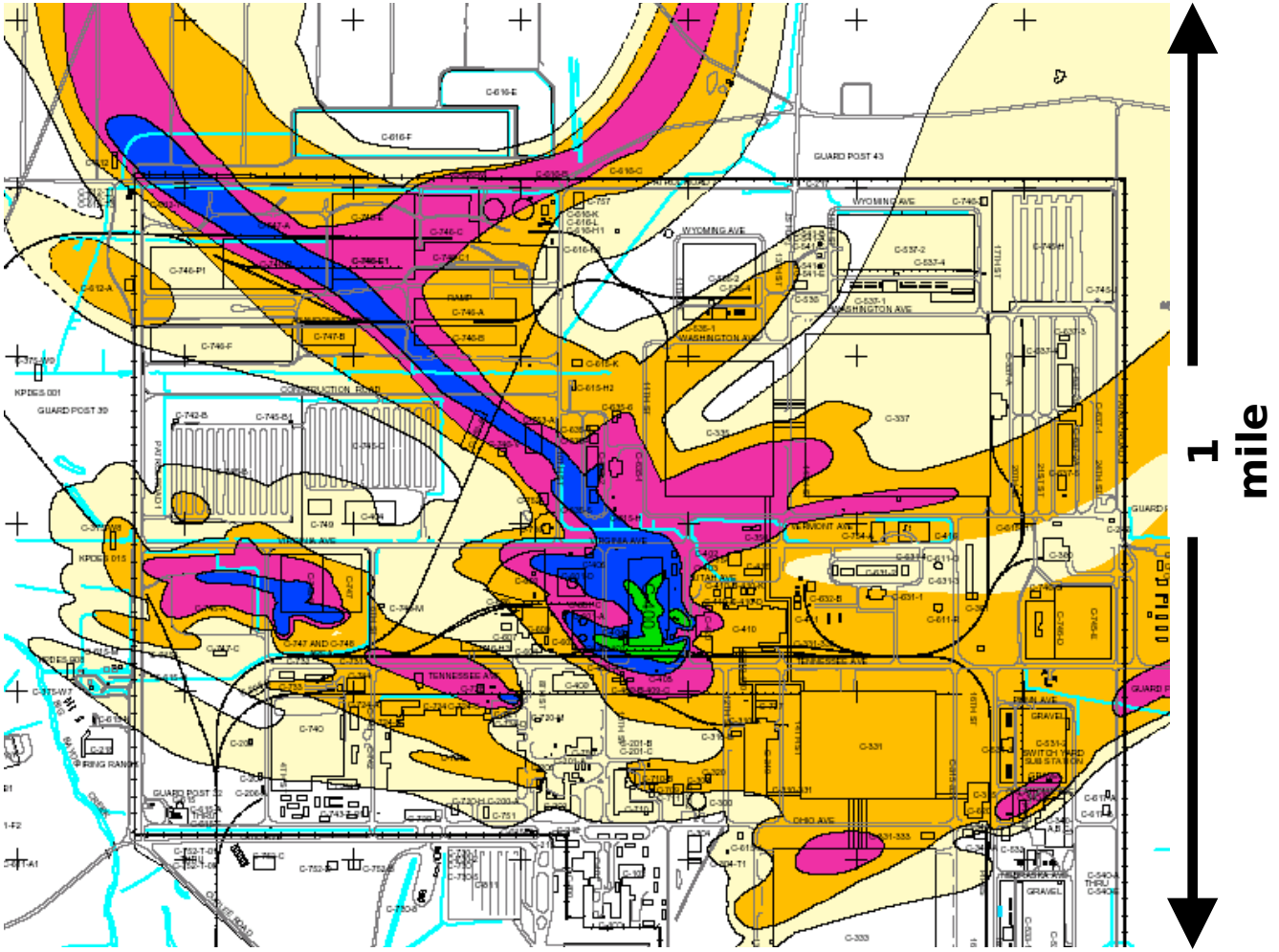
Dissolved TCE

>100 mg/l

10-100 mg/l

1-10 mg/l

TCE Release: 1,000,000 lb?



TCE DNAPL Remediation
DOE - Paducah, KY

THERMAL REMEDIATION services inc.

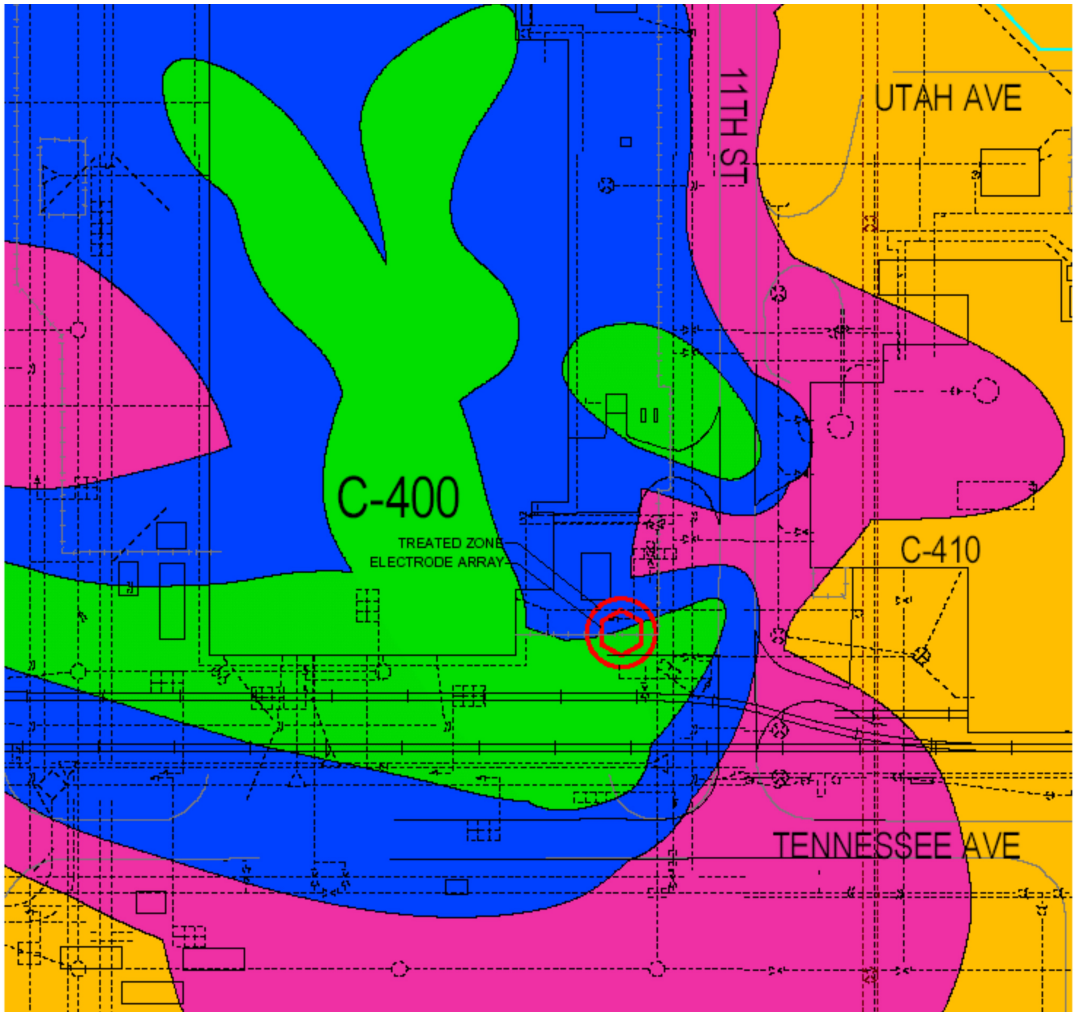
Dissolved TCE

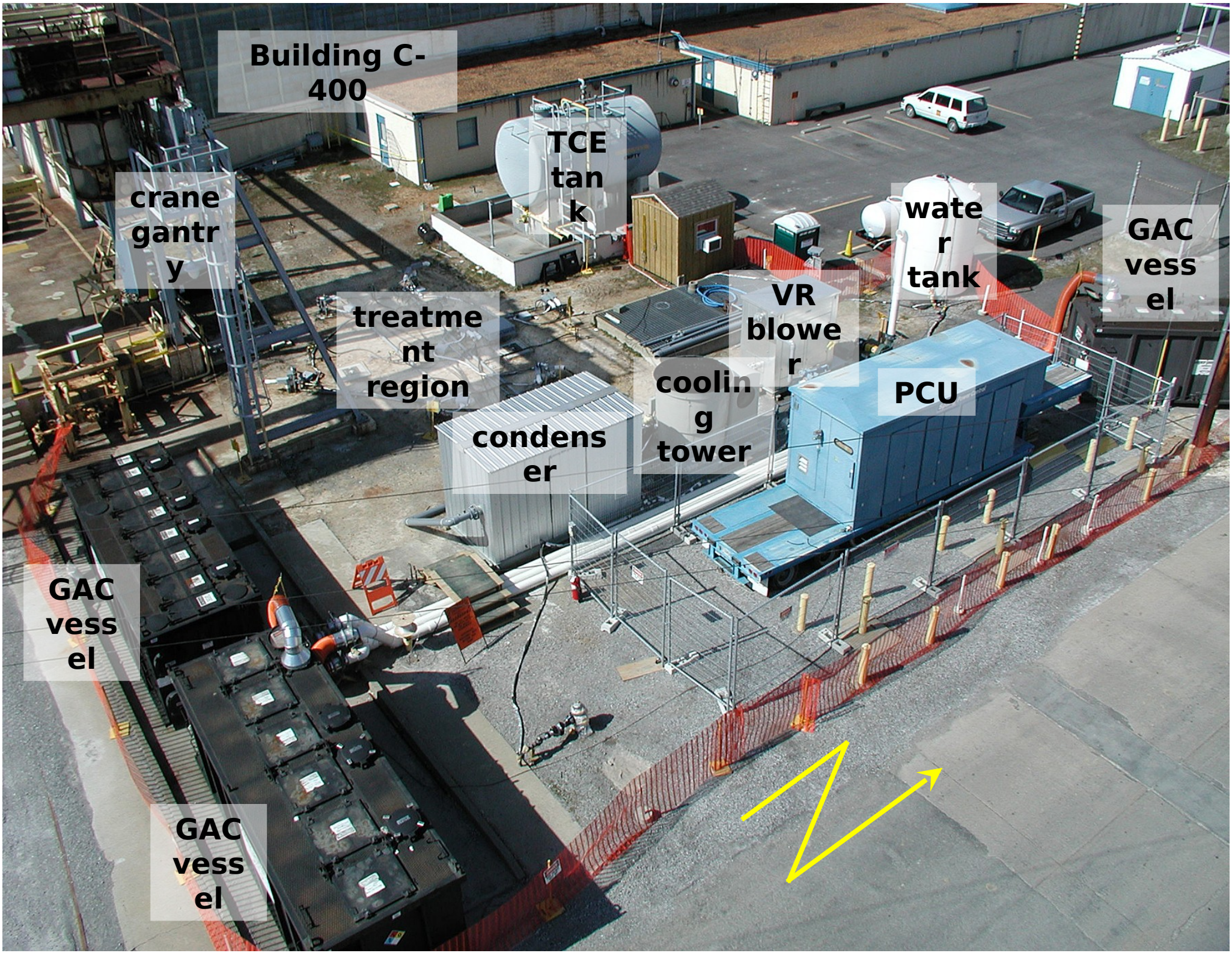
>100 mg/l

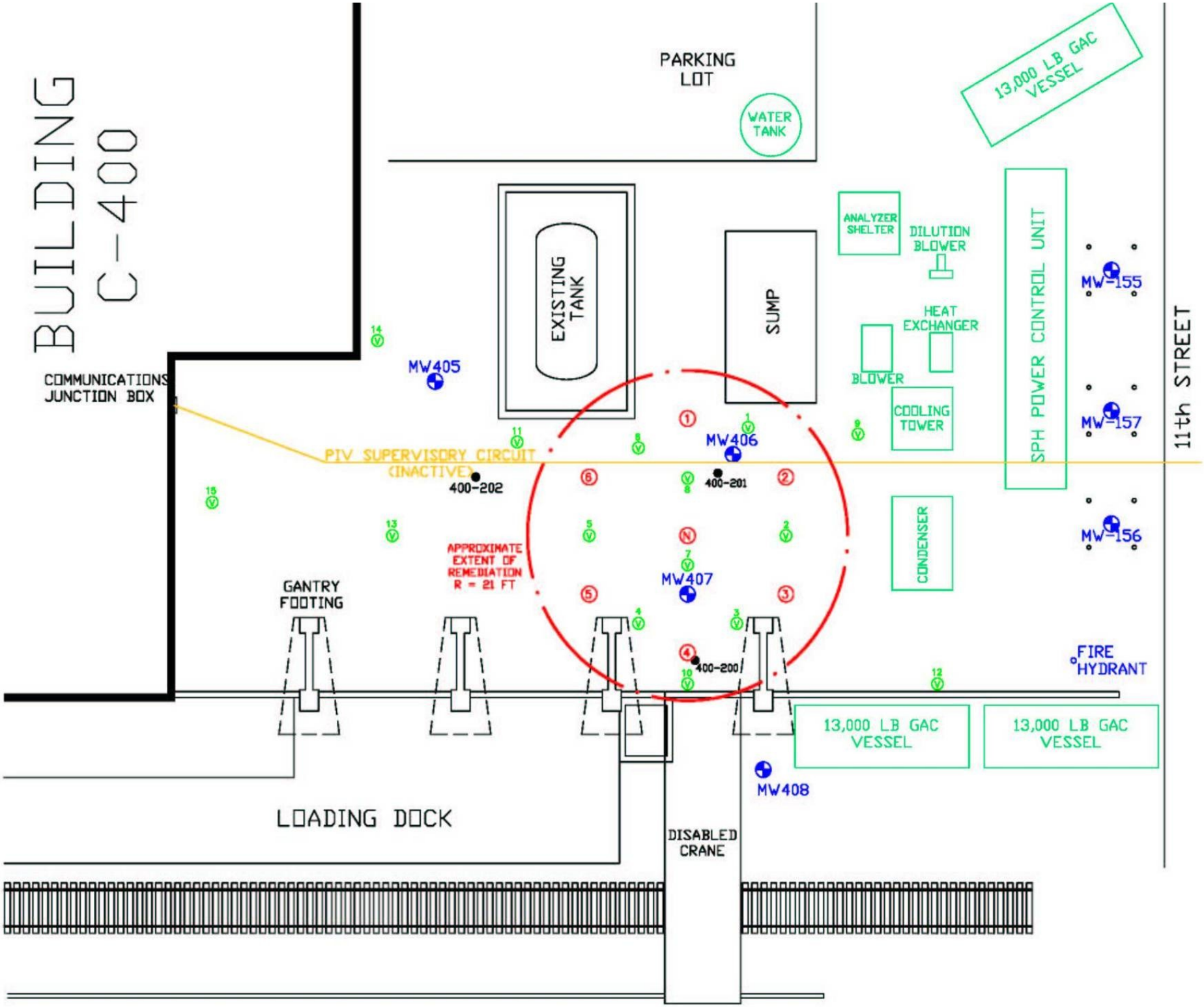
10-100 mg/l

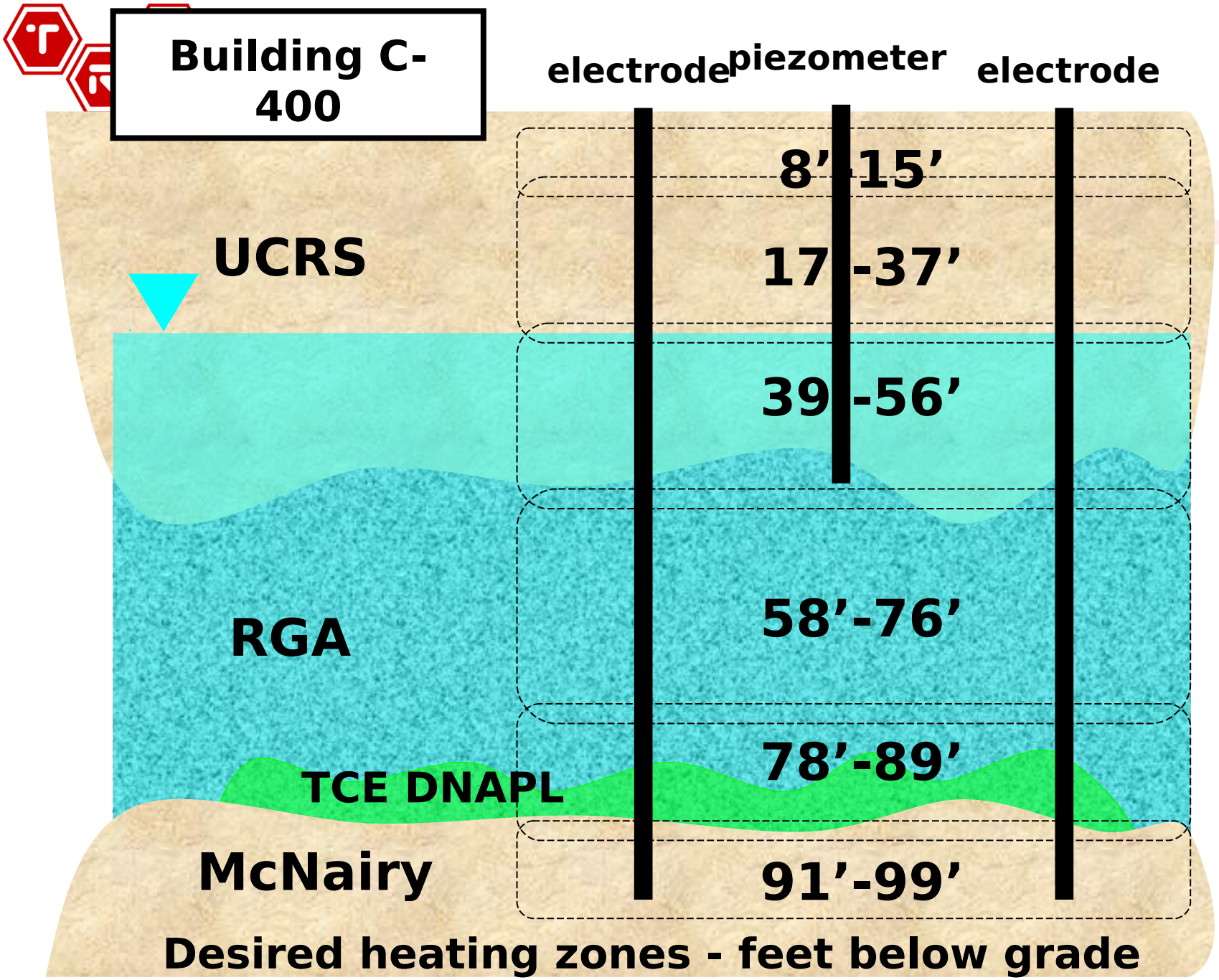
1-10 mg/l

TCE Release: 1,000,000 lb?



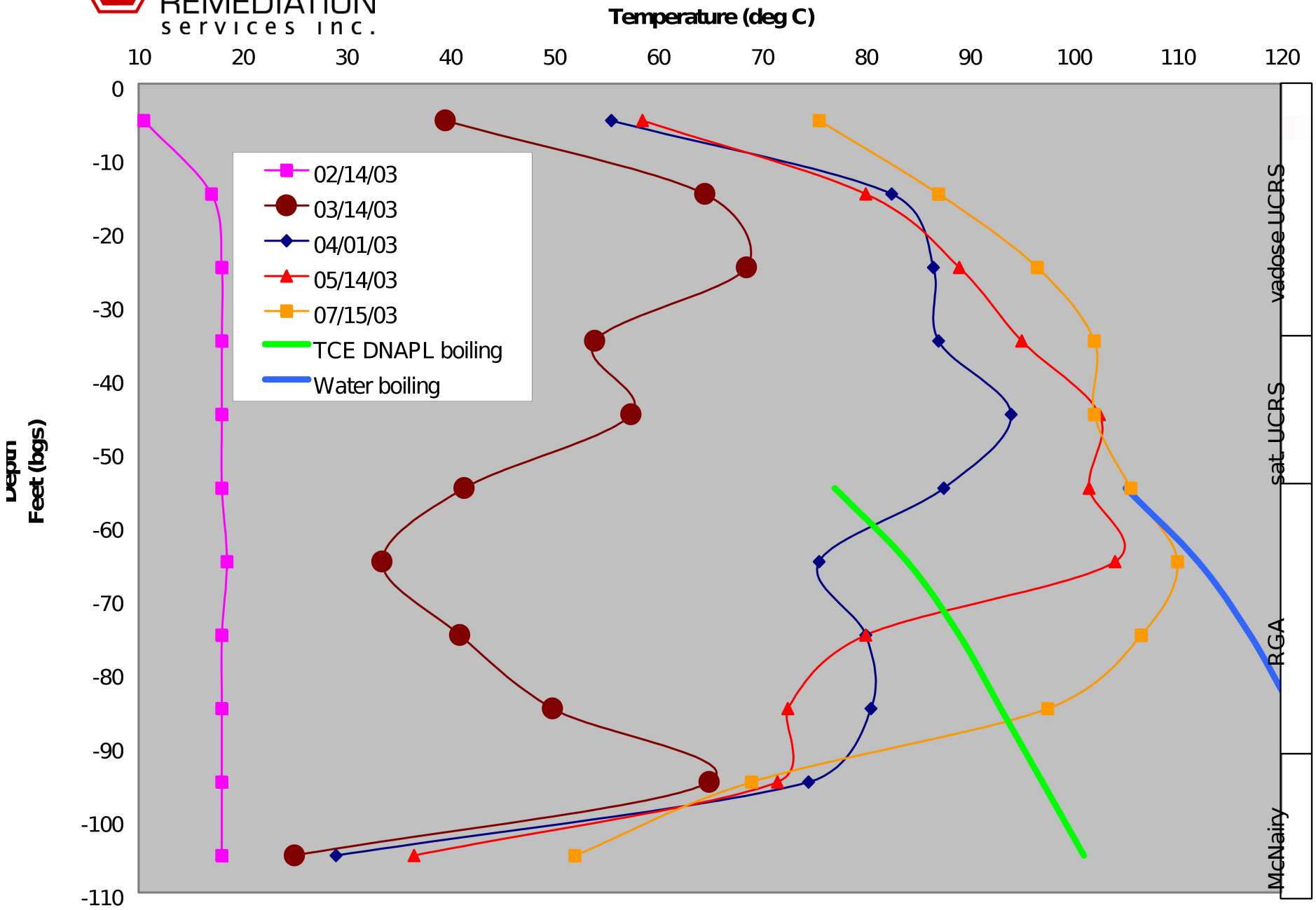

Building C-400
TCE tank
crane gantry
water tank
GAC vessel
VR blower
treatment region
cooling tower
condenser
PCU
GAC vessel
GAC vessel


BUILDING C-400
PARKING LOT
WATER TANK
13,000 LB GAC VESSEL
EXISTING TANK
SUMP
ANALYZER SHELTER
DILUTION BLOWER
HEAT EXCHANGER
BLOWER
COOLING TOWER
CONDENSER
SPH POWER CONTROL UNIT
11th STREET
MW-155
MW-157
MW-156
MW405
MW406
MW407
MW408
COMMUNICATIONS JUNCTION BOX
PIV SUPERVISORY CIRCUIT (INACTIVE)
400-202
400-201
400-200
APPROXIMATE EXTENT OF REMEDIATION R = 21 FT
GANTRY FOOTING
FIRE HYDRANT
13,000 LB GAC VESSEL
13,000 LB GAC VESSEL
LOADING DOCK
DISABLED CRANE

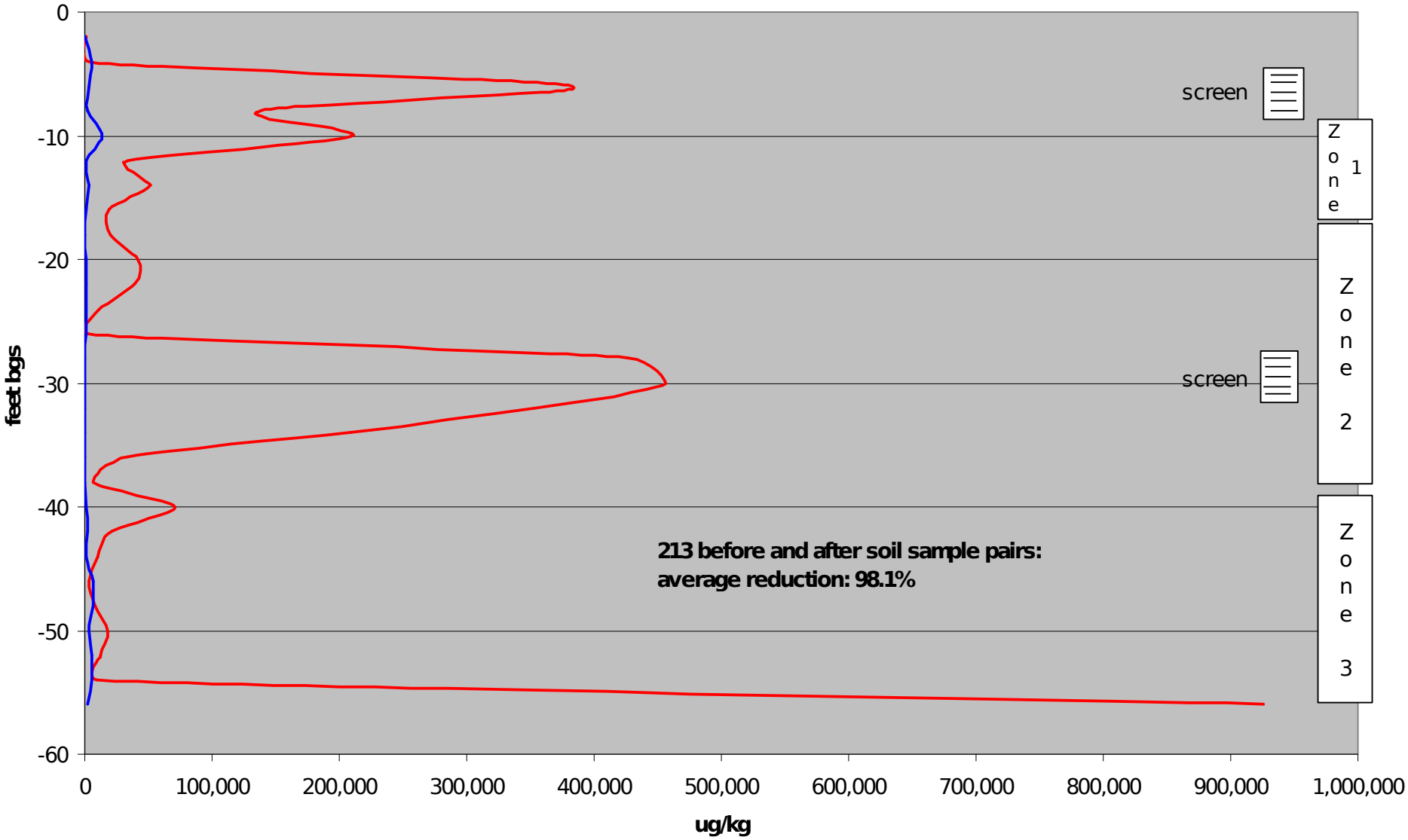

Building C-400
electrode
piezometer
electrode
8’-15’
UCRS
17’-37’
39’-56’
RGA
58’-76’
78’-89’
TCE DNAPL
McNairy
91’-99’
Desired heating zones - feet below grade

THERMAL REMEDIATION services inc.

Treatment Zone Temperature vs. Depth

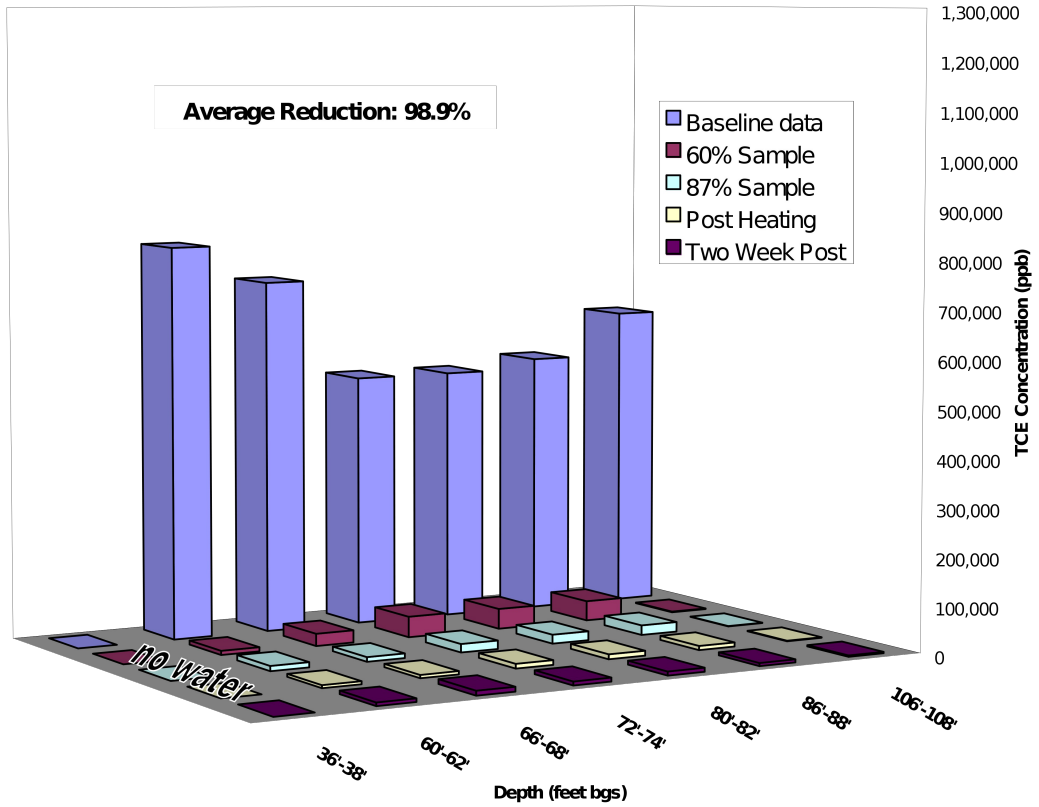


Paducah Soil Results Inside Treatment Area



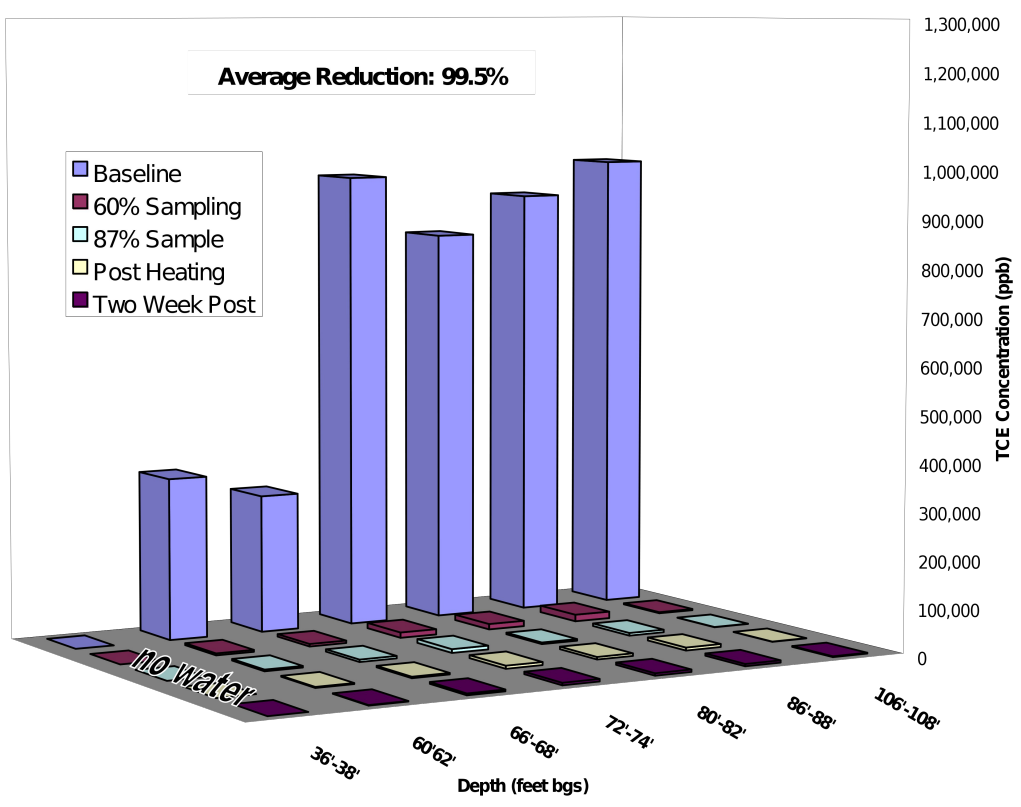
Paducah Groundwater Results Inside Treatment Area

MW-406



Average reduction: 98.9%

MW-407



Average reduction: 99.5%

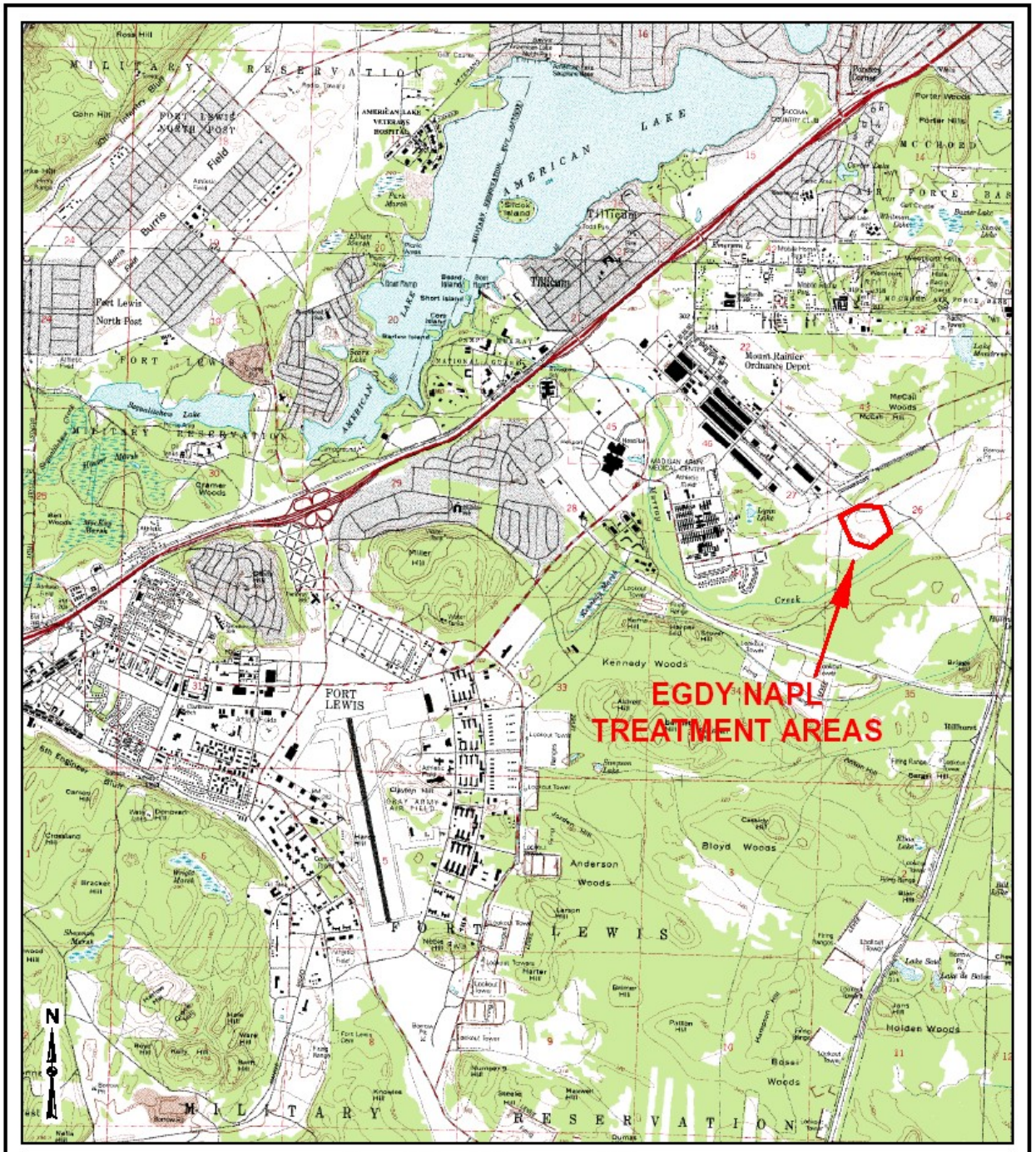
THERMAL REMEDIATION services inc.

Results at Paducah

- Remediation to 100 feet bgs
- Goal was 75% reduction in average TCE concentrations in soil and groundwater
- Achieved ~99% reduction in average TCE concentrations in soil and groundwater
- Operations time was about 8 months

THERMAL REMEDIATION services inc.

In-Situ Thermal Remediation of DNAPL and LNAPL using ERH and MPE at the East Gate Disposal Yard (EGDY)



USGS Quads
47122-A5 Ft. Lewis
47122-B5 Steilacoom

FIGURE 1

THERMAL REMEDIATION services inc. amec CDM

EGDY LOCATION MAP - FORT LEWIS
TACOMA, WASHINGTON

PROJECT SITE

DANGER
HIGH VOLTAGE
KEEP OUT
DANGER
HIGH VOLTAGE
KEEP OUT

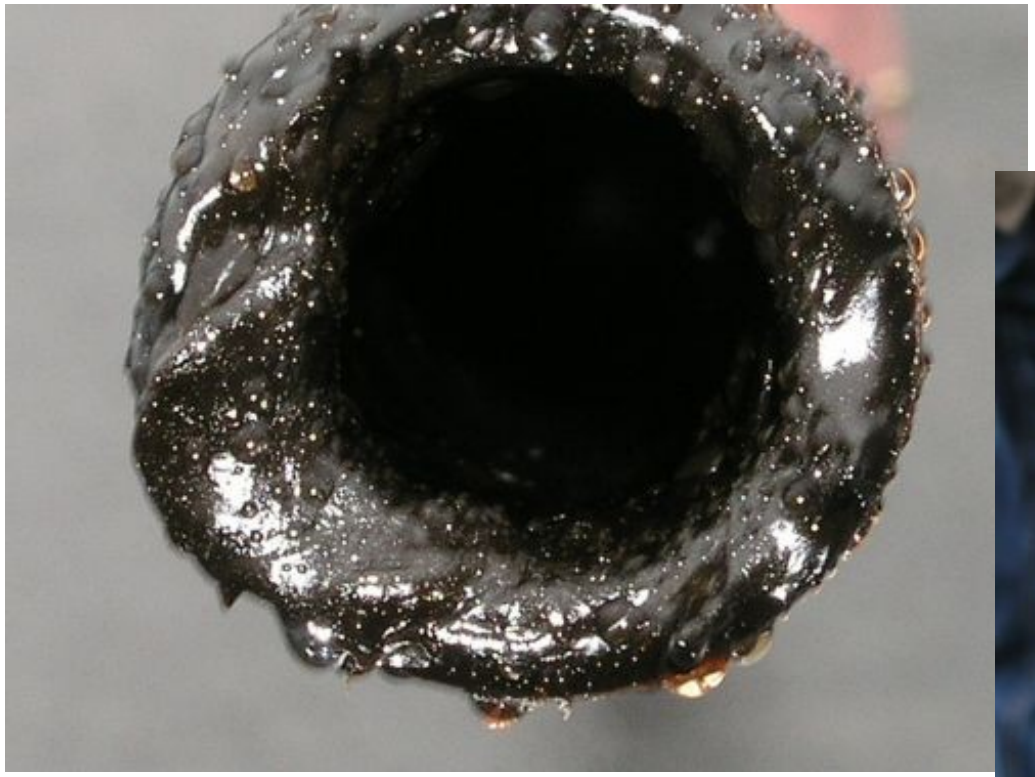
VAPOR

THERMAL REMEDIATION services inc.

Electrode and Co-located VR and MPE Wells

THERMAL REMEDIATION services inc.

NAPL at Bottom of Slurp Pipe



THERMAL REMEDIATION services inc.

Polishing Mechanisms

- **Hydrolysis of Halogenated Alkanes**
  - Compounds such as TCA have a hydrolysis half-life of less than one day at steam temperatures.
- **Iron Reductive Dehalogenation**
  - Steel shot used as electrode backfill provides an iron source for reductive dehalogenation (iron filing wall)
- **Temperature Accelerates Reactions**
  - The above reaction rates are increased by factor of thousands at 100°C (Arrhenius Equation)
- **Bioremediation by Thermophiles**
  - Thermophilic bacteria are the most effective solvent dehalogenators and prefer 40-70°C

Factors Influencing ERH Cost

- Treatment volume (yd^3)
- VOC type (TCE, PCE, etc.) and percentage reduction desired
- Soil total organic carbon (TOC) content
- Presence of oil, grease or other low volatility compounds
- Above grade or below grade piping and electrical distribution
- Location of treatment area with regard to existing structures and whether or not the building is in use.

Factors with Almost No Impact on ERH Cost

- Soil type or heterogeneity
- Presence or distribution of DNAPL
- Degree of water saturation (vadose or saturated zone)
- Electrical conductivity of the subsurface
- Cost of electricity ($ per kilowatt-hour)

www.Thermalrs.com

THERMAL REMEDIATION services inc.

EMPLOYMENT
LOCATIONS
LINKS
SITEMAP
CUSTOMER LOGIN
THERMAL REMEDIATION services inc.
company
technology
solutions
projects
contact
news
Thermal Remediation Services, Inc. is the premier provider of advanced soil and groundwater remediation technologies and solutions.
Featured Project Tour
Get an "up-close-and-personal" tour.
Technical Process Tour
Click here to see the technology in action.
THERMAL REMEDIATION SERVICES
Electrical Resistance Heating
A clear technological breakthrough in the innovative use of electrical technologies for the remediation of soil and groundwater.
CLICK TO LEARN MORE
Thermal update
August 1, 2003 — TRS is pleased to announce the addition of a Featured Project tour on our website. — The tour provides detailed photos and descriptions of our Six Phase Heating remediation system at the U.S. Department of Energy Plant in Kentucky. Start the tour by clicking the Featured Project Tour icon in the left margin on this page. MORE
July 15, 2003 — TRS offers you an easy approach to staying current on news and information regarding our progress deploying Electrical Resistance Heating for the rapid, insitu thermal remediation of soil and groundwater. — You can now simply type your contact information and select your categories of interest in a simple sign-up form and begin receiving TRS news and updates. Join our mailing list today. MORE
May 13, 2003 — TRS announces the successful completion of a guaranteed fixed price full scale remediation project with Clayton Group Services using Electrical Resistance Heating (ERH) for the rapid remediation of PCE in the vadose zone. — Thermal Remediation Services (TRS), working for Clayton Group Services, successfully completed a guaranteed, fixed price rapid remediation of Tetrachloroethene (PCE) in soil at a drycleaning facility located in a suburb of Chicago. MORE
April 2, 2003 — TRS announces the successful completion of the full-scale TCE DNAPL remediation using ERH at Air Force Plant 4 in Fort Worth, Texas. TRS, as a subcontractor to the Austin, Texas office of URS Corp., deployed ERH at Air Force Plant 4 for remediation of the TCE DNAPL source area underneath Building 181 from April to December of 2002. — The cleanup goals established for this site were an average 90% reduction in TCE concentrations in soil and groundwater. The groundwater goal was met following 4 months of ERH operations. The soil goal was met in December 2002. The cleanup goals were based on a 95% Upper Confidence Limit (UCL) statistical analysis. MORE
April 1, 2003 — TRS announces that its senior management team is the most experienced group of professionals in the world at providing Electrical Resistance Heating (ERH) for the rapid remediation of soil and groundwater. — TRS also announces that it has MORE THAN 10 times the remediation capacity of any other provider of ERH based on a specialty equipment fleet and the size of our staff. MORE
February 7, 2003 — TRS receives Electrical Resistance Heating License from